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EXPERIMENTAL STUDY ON SUPERLUBRICITY OF AG NANOMETER-THICK-LAYERS BY SLIDING ON A MACROSCOPIC SYSTEM

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ABSTRACT

The experimental study on the Ag film was carried out using a diamond pin-on-plate type tribometer under ultrahigh vacuum (UHV) conditions. The coefficient of friction varied with the film morphology in nanometric scale up to 170 nm, and superlubricity as minimum coefficient of friction 0.007 was obtained on 5-nm Ag film with network structure. RHEED and STM observation of the film showed that the film morphologies changed drastically during rubbing, and that the superlubricity of this system is attributed to the lamella gliding of Ag (111) sheets.

INTRODUCTION

The concept of a superlubricity was theoretically discussed by Hirano and Shinjo [1]. Martin et al. [2] showed extraordinary low friction coefficient of molybdenum disulfide (MoS_2), which was less than 0.002 (milli-range), in ultrahigh vacuum (UHV) condition. They pointed out that the milli-range coefficient of friction was attributed to the mechanism of the superlubric state as Hirano et al. discussed [1]. The sliding plane of MoS_2 is c-plane. Recently, Goto et al. [3-5] showed that the milli-range friction of epitaxial Ag film, and concluded that the low friction coefficient was attributed to inter-layer shearing between Ag (111) planes parallel to the sliding direction. This paper provides another example different from the superlubricity of MoS_2, because the interaction between MoS_2 layers is Van der Waals interaction, whereas the interaction between Ag (111) planes is metallic bond.

METHODS

The pin was made of the single crystal diamond, and was polished convexly with a curvature radius of 3 mm and with 2.6 nm rms finish, and the crystallographic orientation of the sliding surface was (111) surface. Silver films were deposited on the Si (111)7×7 clean surfaces with the surface roughness of 0.68 nm root-mean-square (Rrms), using water-cooled Knudsen-Cell under the pressure of less than 5×10^{-8} Pa. The crystallographic orientation of the film was observed using reflection high energy electron diffraction (RHEED) and X-ray diffraction (XRD). The morphology of the films was also observed *in-situ* using scanning tunneling microscopy (STM) and *ex-situ* atomic force microscopy (AFM).

The frictional experiments for the Ag films against single crystal diamond sphere were carried out under the pressure of less than 4×10^{-8} Pa. The sliding speed and normal load were 1.0 mm/s and 250 mN respectively, and maximum Hertzian contact pressure was 430 MPa. The 4×4 mm^2 ground surface was prepared by multi-sliding the worn track (35×4000 μm^2) in feed increments of 20 μm. Each worn track was slid under 10 reciprocal-sliding cycles at a speed of 1.0 mm/s. The center of the rubbed area was observed by RHEED and STM. The all experimental process was carried out under an UHV environment.

RESULTS AND DISCUSSION

The Ag films were grown epitaxially on the Si (111) 7×7 surface, and were classified the following 4 steps as the thickness increase: the completion of percolation texture (~ 0.1 nm), Ag islands formation (0.1 ~ 1.5 nm), network structure formation (2 nm ~), and completion of the continual film (~ 170 nm). The coefficient of friction varied with the film morphology in nanometric scale, and the minimum coefficient of friction was 0.007 on 5-nm Ag film with network structure.

The network morphologies of the film changed drastically during rubbing by diamond surface, as shown in Fig. 1. The network structure disappeared by rubbing, and a lamellar structure appeared instead. The each step height of lamellar was 0.25-0.30 nm, which corresponds to the spacing between Ag (111) planes. These results indicate that milli-range friction coefficient of the epitaxial Ag film is attributed to the lamella gliding of Ag (111) facets. The change on the crystallographic orientation of the surface was observed using RHEED before and after rubbing on the film, and the results are shown in Fig. 2. Figure 2 shows that the spots of 1st Laue-zone originated from Ag (111) top layer became streaked spot than that before rubbing. This result indicates that the Ag (111) facets, shown in Fig. 1, have rotated within the same plane around the normal axis of Si (111) surface.

In the case of the superlubricity of MoS_2 in UHV condition reported by Martin et al. [2], the shear plane is between c-planes of MoS_2, and the interaction is weak Van der Waals interaction between S-S. The presented results, however, show that the milli-range friction is obtained even by strong interaction of metallic bond between Ag (111) planes. Hirano and Shinjo [1] predicted theoretically that the superlubric state will appear even if the interaction between the sliding interfaces is strong enough to metallic bond, when the commensurability of atomic arrangement between the planes is satisfied. The result presented here gives another example of the superlubricity that is different kind of interaction from Van-der-Walls interaction.

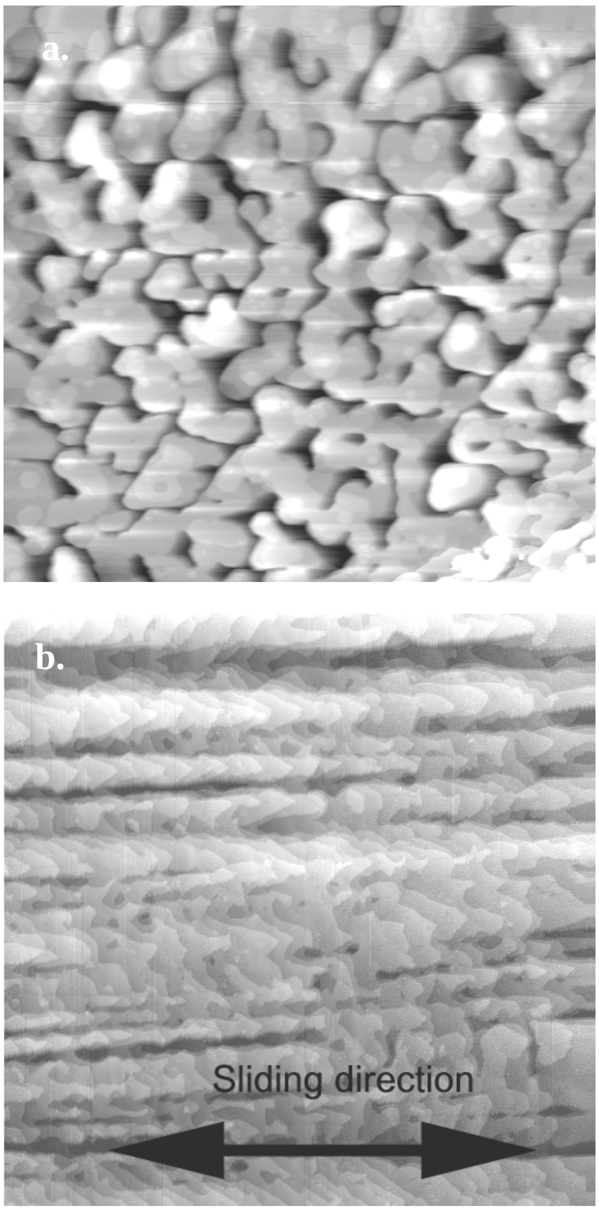

Fig. 1 Film morphology of 5 nm-Ag film before and after rubbing.
a. STM image of 5 nm-Ag film before rubbing
b. STM image of 5 nm-Ag film after rubbing
Scanning area of 1×1 μm^2

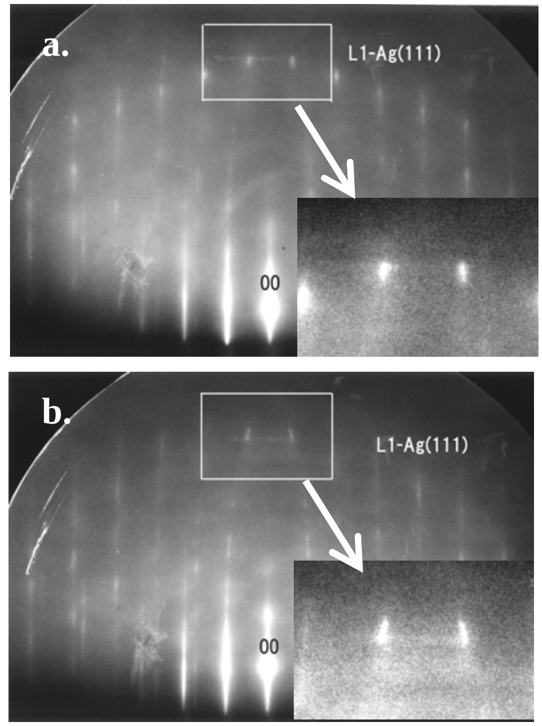

Fig. 2 RHEED pattern of 5 nm-Ag film (a) before and (b) after rubbing

CONCLUSIONS AND FUTURE WORK

This paper demonstrates that the milli-range friction coefficient appears by Ag epitaxial layer with a thickness of 5 nm in average, maintaining atomically flat layer of Ag (111) facets parallel to the pin sliding direction in contact area. To demonstrate the actual evidence of incommensurability during sliding is future work of this study.

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